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The Effect of Changing Trombe Wall Component on the Thermal Load

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Abstract

In this research, effects of changing Trombe wall components on the thermal load in the building has been studied and stimulating it with the use of Java language to calculate thermal load, solar gain and auxiliary energy that have to be used according to these changes.. Besides, illustrating diagrams have been drawn for the following indications changes:

1- Wall type (thermal mass).

2- Thermal mass thickness.

3- Trombe wall area by total wall area.

4- Layers count of glass coat (one layer- two layers or three layers).

Chosen the best model to be applied as the designing model for any building in Syria that includes passive solar systems. The aforementioned program can be applied to include other important changes. Also, an important result, which is energy saving valued by 83%, has been obtained when using Trombe wall. In addition to avoid the emission of environment-unfriendly gases.

Key word: Passive solar building- Trombe wall-Thermal mass –solar gain.

1- *Introduction*

Principle of the passive solar heating depends on benefiting from the solar energy available in nature as the thermal flow amount is controlled without using any additional auxiliary electrical or mechanical means. The passive solar heating methods rely on receiving of the solar radiation and transforming it into heat , absorbing it and storing it to achieve heating of the building based in providing heat to the building on structure of the building itself. Trombe Wall is among the passive solar heating systems which benefits from the indirect solar gain. Trombe Wall (the name was taken from the French scientist Michel Trombe who suggested it in 1880) consists of transparent cover (one, two or three layers of the transparent glass or plastic) and a 5-20 [Cm] deep air vacuum in between the transparent cover and the storage mass (which must have a high thermal capacity) [4] which is coated with a black or a selective paint. Thickness of the storage mass is between 6-18 [in] and the black coated part of the storage mass is heated by the solar radiation penetrating through the glass layers.

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2- *Heat-storage walls (Trombe wall) :*

Figure (1) shows Trombe wall which is directed southwards because the sun takes its lowest sky position in winter (in the northern hemisphere). The solar radiation enters through the transparent cover and then to the inside of the building causing to heat the wall and the room's air. When the solar

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radiation disappears, the thermal inertia of the studied ambient medium helps to storage such heat for a longer period of time.

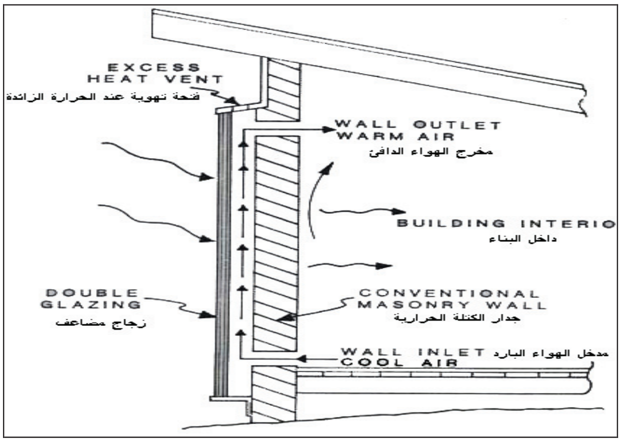


Fig.1. Trombe wall structure

The studied model is a 20 [m^2] area room in the city of Damascus. The model consists of four external walls insulated by 5 [Cm] thick stereopore, the heat transfer to wall coefficient [W/m^2] (U=0.506) while in the ceiling and the flooring a 3 [Cm] thick foam layer is placed as an insulator under the slabs, the heat transfer to ceiling and floor coefficient [W/m^2] (U=0.661). The southern wall of the house is utilized to represent Trombe wall.

3- The studied model's thermal load :

-Calculating the monthly thermal load of the house:

The monthly thermal load is calculated by the (Degree-Day) method [2]:

A. for a house without Trombe wall :

$$L = [\sum_{i=1}^{i=n} (UA)_i + M.C_p].DD - Q_{IH} \qquad [GJ] \quad (1)$$

Where:

$(UA)_i \left[\frac{W}{{}^oC}\right]$: External walls' thermal loss coefficient multiplied by the wall surface area [m^2]

Q_{IH} [MJ]: Internal heat amount resulting from heat of the devices, people and lighting.

$\left(M.C_p\right)\left[\frac{J}{\sec.{}^oC}\right]$: Thermal load resulting from air infiltration.

DD: (Degree-Day) $\left[{}^oC.day\right]$ which transforms into $\left[{}^oC.\sec\right]$ so the units become homogenous.

$$DD = N.(\bar{t}_i - \bar{t}_o) \qquad (2)$$

$\bar{t}_i$ [°C]: building's internal temperature average,($\bar{t}_i$ = 20 °C)

$\bar{t}_o$ [°C]: external temperature monthly average to be taken from the Meteorology Authority [3]

B. for a house with Trombe wall :

$$L_{TW} = \left[\left(\Sigma\left(UA\right)_i\right)_{TW} + U_w A_r + \left(M.C_p\right)_{TW}\right].DD \qquad (3)$$

Where:

L_{TW} $[GJ]$:Monthly thermal load of the system which contains Trombe wall

$\left(\Sigma(UA)_i\right)_{TW}\left[\frac{W}{^oC}\right]$: thermal loss coefficient multiplied by the external cover area of the studied model (excluding Trombe wall) .

$U_w A_r\left[\frac{W}{^oC}\right]$ thermal loss coefficient from Trombe wall [1] multiplied by the solar radiation receiving surface area [m^2]

$\left(M.C_p\right)_{TW}\left[\frac{J}{\sec.^oC}\right]$: thermal load resulting from air infiltration from the building in case Trombe wall system is used.

$$\bar{S} = \bar{H}_T.(\overline{\tau\alpha}) \qquad (4)$$

$\bar{S}\left[\frac{MJ}{m^2}\right]$:net solar radiation intensity which Trombe wall absorbs.

$\bar{H}_T\left[\frac{MJ}{m^2}\right]$:monthly solar radiation average falling on Trombe wall.

$\left(\overline{\tau\alpha}\right)$: Approximate average of multiplying the glass penetration coefficient (τ) by the absorption coefficient of the southern absorbent surface (α) as their average value may be accepted :$\left(\overline{\tau\alpha}\right) = 0.75$ [1].

AUX_{TW} $[GJ]$:the auxiliary energy needed to heat the house besides the solar gain in Trombe wall system

The total monthly thermal load of the studied model : L= 8.072 [GJ]

For the purpose of the researching, the following components of Trombe wall have been changed:

1- kind of the wall (cement – brick– water tank)
2- storage mass thickness : (10-20-30-45 Cm)
3- Trombe wall area of the wall's total area: (25-50-75-100%)
4- Number of the glass cover layers (one layer– two layers– three layers)

4- Calculating the solar heating system performance indicators:

4-1 Solar load ratio:

SLR is ratio of the solar energy absorbed by Trombe wall to the monthly load of the building which contains a Trombe wall in absence of the solar gain and it is calculated : [1]

$$SLR = \frac{\bar{S}.N.A_r}{L_{TW}} \qquad (5)$$

Where:

N: number of days of the studied month

$A_r\left[m^2\right]$:Trombe wall's receiving surface

4-2 Solar heating fraction :

SHF by this coefficient it is possible to know the fraction by which the solar radiation contributes to covering part of the building's thermal load or to know the energy saving percentage. SHF is included in calculating of the auxiliary heat amount to cover the overload probabilities and it is calculated by its relation with SLR [1]:

In Trombe wall system:

SHF = 0.7197(SLR) for SLR $\le$ 0.5

SHF = 1.007 –1.119 exp [–1.0948(SLR)] for SLR > 0.5

SHF value could be directly read from the diagram in Figure (3) as a dependent of SRL [1]

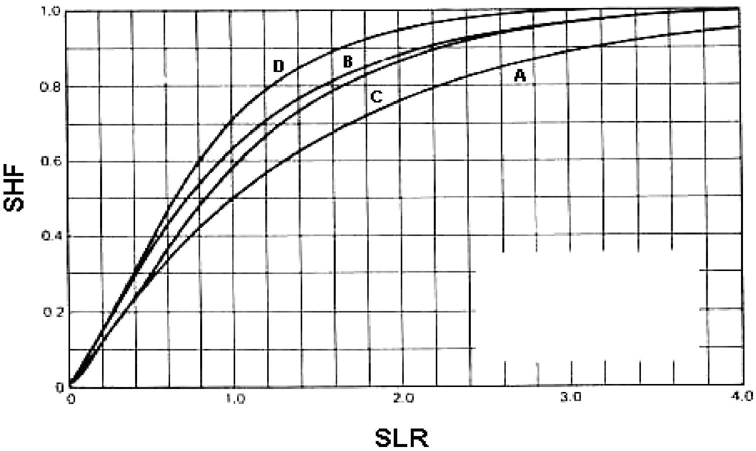


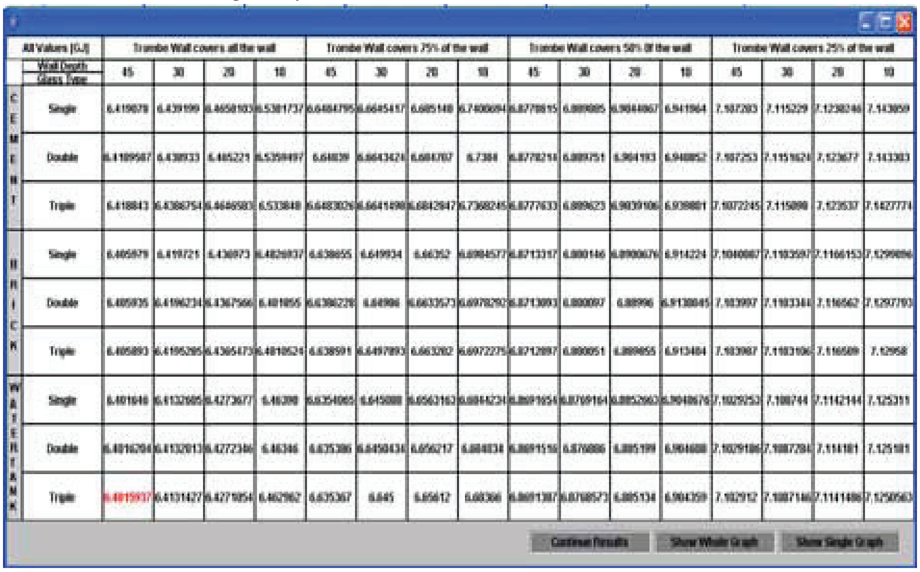
Fig.2. chart between: SLR-SHF

The auxiliary energy could be calculated from the equivalent (6):

$$L_{aux,TW} = (1 - SHF) L_{TW} \qquad (6)$$

The program calculates the thermal load of the model which contains a Trombe wall as for all the indicators intended to be changed in the months of heating (January, February, March, November and December) as showing in Table (1).

Table .1.thermal load changeability with considered indicators.



All Values [GJ]		Trombe Wall covers all the wall				Trombe Wall covers 75% of the wall				Trombe Wall covers 50% of the wall				Trombe Wall covers 25% of the wall			
	Wall Depth / Glass Type	45	30	20	10	45	30	20	10	45	30	20	10	45	30	20	10
CEMENT	Single	6.419079	6.439199	6.4658103	6.5381737	6.6484795	6.6645417	6.685148	6.7406094	6.8778815	6.889085	6.9044067	6.941964	7.107203	7.115229	7.1238246	7.143059
	Double	6.4189587	6.438933	6.465221	6.5359497	6.64839	6.6643424	6.684707	6.7384	6.8778214	6.889751	6.904193	6.940852	7.107253	7.1151624	7.123677	7.143383
	Triple	6.418843	6.4386754	6.4646583	6.533848	6.6483026	6.6641498	6.6842947	6.7368245	6.8777633	6.889623	6.9039106	6.939881	7.1072245	7.115098	7.123537	7.1427774
BRICK	Single	6.405979	6.419721	6.436973	6.4826937	6.638655	6.649934	6.66352	6.6984577	6.8713317	6.880146	6.8900676	6.914224	7.1040087	7.1103597	7.1166153	7.1299096
	Double	6.405935	6.4196234	6.4367566	6.481855	6.6386228	6.64986	6.6633573	6.6978292	6.8713093	6.880097	6.88996	6.9138045	7.103997	7.1103344	7.116562	7.1297793
	Triple	6.405893	6.4195285	6.4365473	6.4810524	6.638591	6.6497893	6.663202	6.6972275	6.8712897	6.880051	6.889855	6.913484	7.103987	7.1103106	7.116509	7.12958
WATER TANK	Single	6.401640	6.4132605	6.4273677	6.46398	6.6354065	6.645088	6.6563163	6.6844234	6.8691654	6.8769164	6.8852663	6.9048676	7.1029253	7.108744	7.1142144	7.125311
	Double	6.4016294	6.4132013	6.4272346	6.46346	6.635386	6.6450436	6.656217	6.684034	6.8691516	6.876886	6.885199	6.904688	7.1029186	7.1087284	7.114181	7.125181
	Triple	6.4015937	6.4131427	6.4271054	6.462962	6.635367	6.645	6.65612	6.68366	6.8691387	6.8768573	6.885134	6.904359	7.102912	7.1087146	7.1141486	7.1250563

Contineu Results | Show Whole Graph | Show Single Graph

The program shows the following diagrams which indicate the wall's performance with changing of the aforesaid indicators.

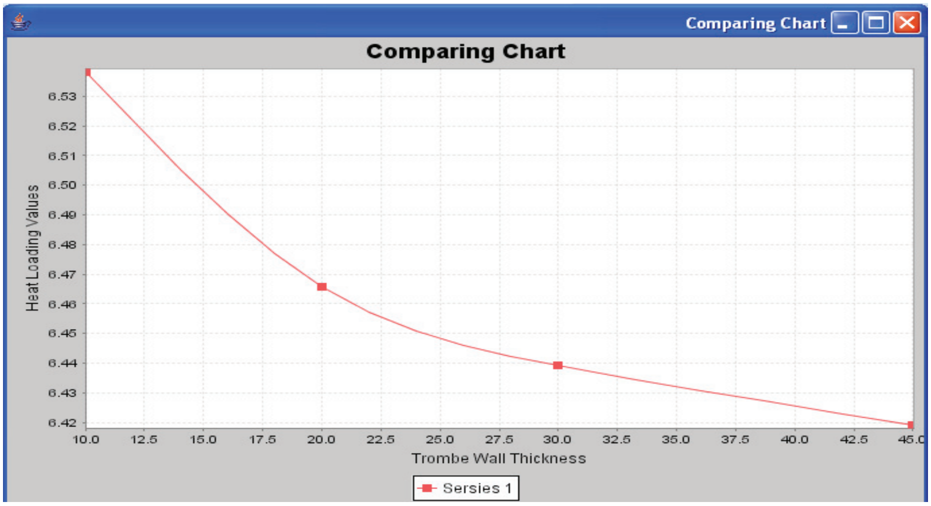


Fig.3. the change of the thermal load when changing of the wall thickness for the inserted indicators.

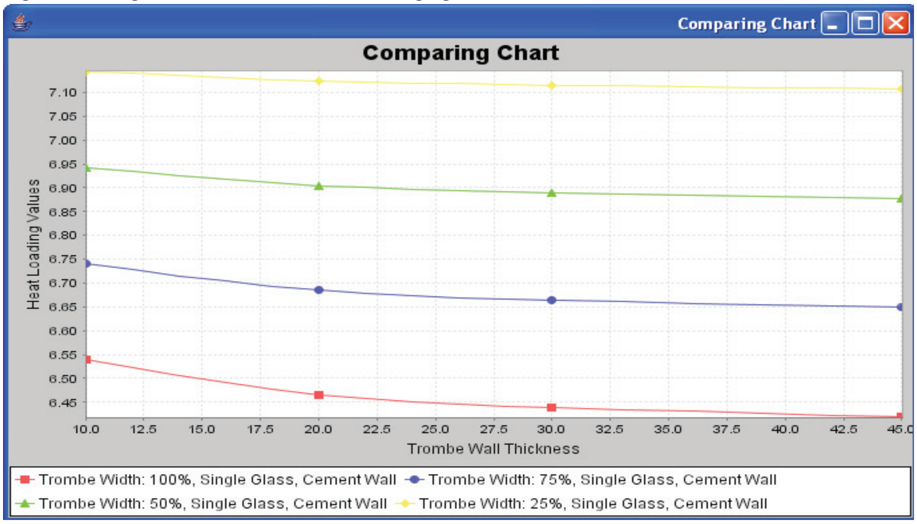


Fig.4. the change of the thermal load when changing of the relative Trombe wall area.

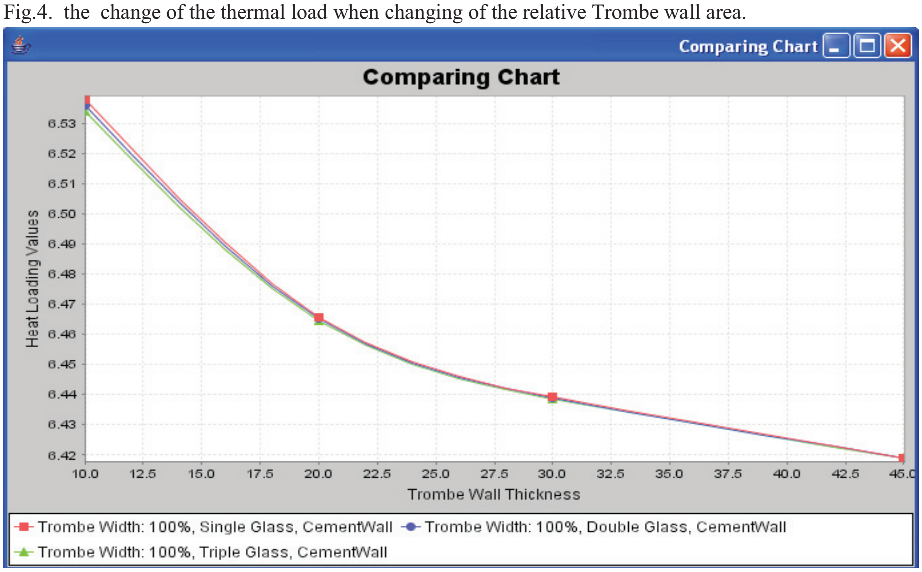


Fig.5 . the change of the thermal load when changing number of the glass layers.

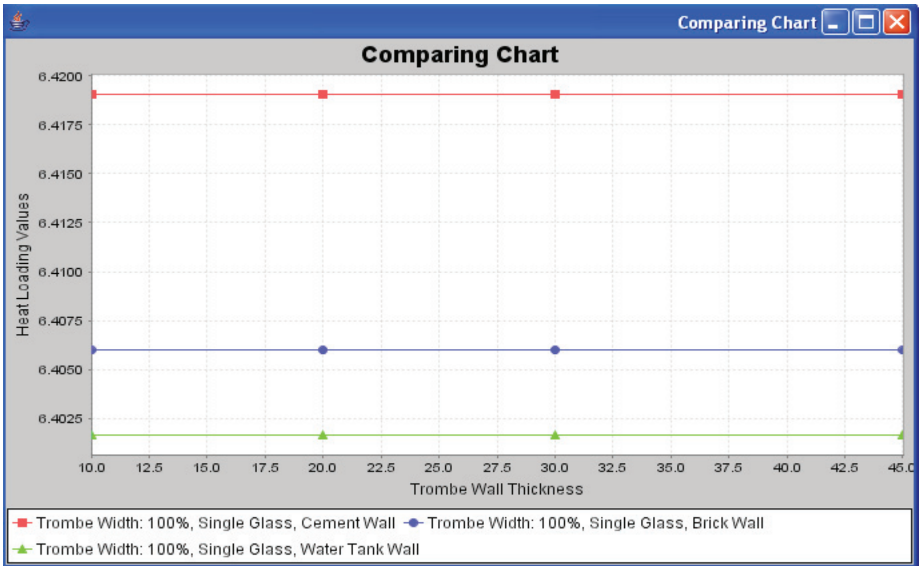


Fig.6 the change of the thermal load when changing of the wall kind.

To know the relation between SLR and SHF it was taken as an example a model of Trombe walls models shown on a window of the program in figure (7) at Damascus city, ratio of Trombe wall area to the whole wall is 100% and it consists of three glass layers, as material of the storage mass is cement whose thickness is 45 [Cm] . Table (2) shows results of this relation and displays the evaluation of Trombe wall performance and estimation of the solar energy which it receives and stores and its contribution to the thermal load covering and the auxiliary energy calculating .

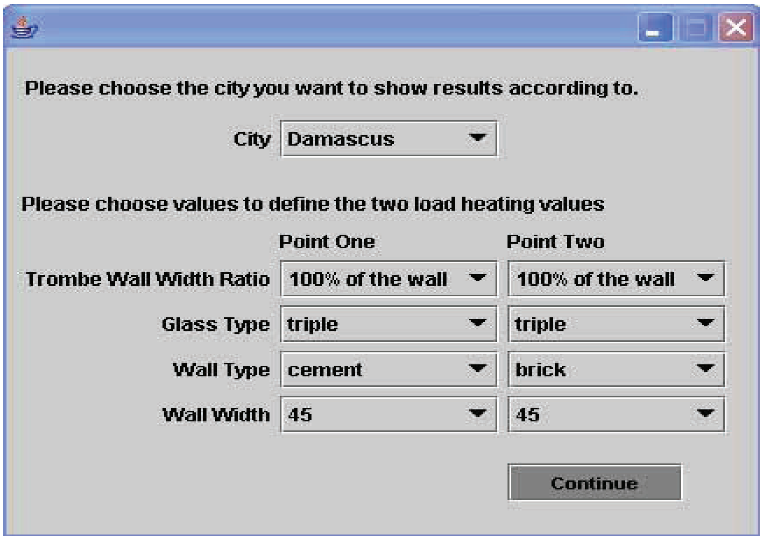


Fig.7. one of the program's windows.

Table .2 the solar thermal gain and the auxiliary extra energy that should be provided.

	S = H * (alpha*T)	DD = N * (Ti - T0)	LTw	Ar * S * N	SLR = SNAr / LTw	SHF	AUX = (1-SHF)*LTw
January	12.1045	423.98699951171875	1.6368416547775269	5.665792499999999	3.461417592509313	0.981704393411338	0.02994701096374...
February	13.66575	336.0	1.2971596717834473	5.739615	4.424759968637795	0.9981892913488484	0.00234877823962...
March	15.066	306.0010070800781	1.1813457012176514	7.00569	5.930262405643842	1.0053049039148785	-0.00626692543521...
April	15.09075	-	-	-	-	-	-
May	15.63075	-	-	-	-	-	-
John	16.209	-	-	-	-	-	-
July	16.57125	-	-	-	-	-	-
August	17.016750000000002	-	-	-	-	-	-
September	17.226750000000003	-	-	-	-	-	-
October	16.28625	-	-	-	-	-	-
November	14.67075	145.1699981689453	0.5604423880577087	6.601837499999999	11.779689831955052	1.0069971946128262	-0.00392152445851...
December	13.629000000000001	342.02301025390625	1.320412039756775	6.337485000000001	4.799626790109692	1.0011551595454218	0.00152528657161...
Annual	183.2475	1553.1810150146484	5.996201984000001	31.35042	30.395752588895627	4.993350942833313	0.02056205273002...

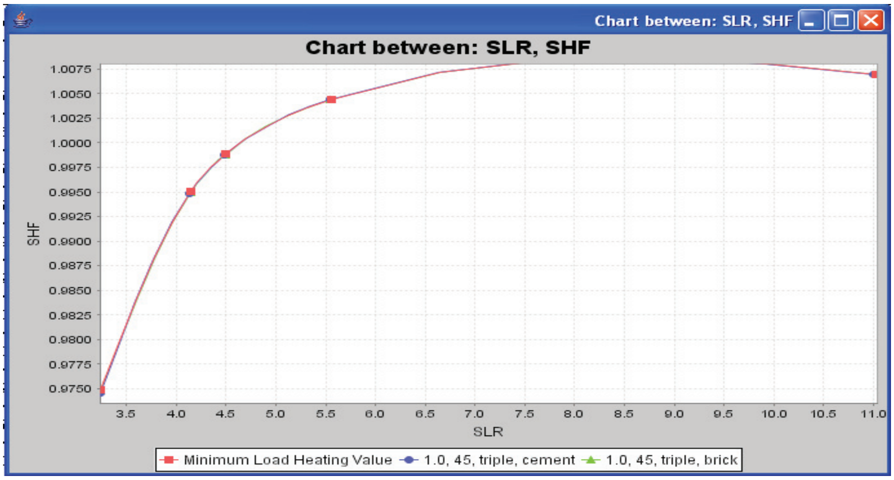


Fig.8 chart between: SLR-SHF

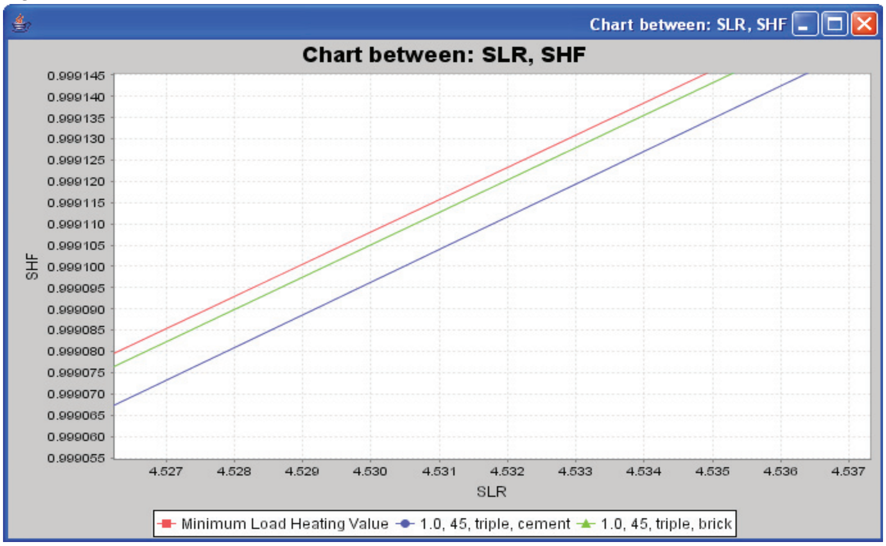


Fig.9 a clarification of the relation between SLR and SHF for part of Figure (8)

5- Solar energy contribution percentage to the solar house load covering SHF

The average values for percentage of the solar energy annual contribution to coverage of the thermal load to heat the solar house by the passive solar heating system which contains Trombe wall as a main element in it in the model example stated in Figure (7) and Table (2) have reached $\overline{SHF} = 0.83$ i.e. it saves energy in the house at 83% which means that Trombe wall allows to transform the solar radiation into heat and it covers 83% of the annual load free of charge.

6- Results and discussion:

1- It is preferred to use the high thermal capacity materials as the diagram SLR-SHF shows the water-tank wall's high efficiency because it has a large thermal capacity and such capacity holds density of the heat that is absorbed during the day to radiate it in the night.

2- The total solar gain increases when Trombe wall area increases.

3- The use of Trombe wall (water tank) that is extended on the wall whole area at 45 [Cm] thick storage thermal mass and which is equipped with three layers of glass does reduce the thermal load as much as possible and it is the best model.

4- It is concluded from the previous diagrams that it is possible economically to use a 20-45 [Cm] thick storage mass Trombe wall paying attention to the following: when wishing to save heat during the night, the big thicknesses are taken 45 [cm] because the thick walls give heat at night and reduce fluctuation between day and night. But if the required is to heat during the day it is better to select the lesser thicknesses within the said range.

5- Having regained the added cost resulting from Trombe wall use we obtain an amount of the free energy which is an economical matter.

6- The annual energy saving percentage is 83% followed by the environment protection from carbon emission.

7- From the economical view : 1- it is possible to use the double glass instead of the triple one in case the cement wall extended on the whole wall is 30 cm thick , 2- using of a 20 [Cm] thick cement wall with one glass layer instead of a 10 [Cm] thick wall with three glass layers and, 3 - it is possible to use a 45 [Cm] thick cement wall with one glass layer instead of a 20 [Cm] thick water wall with three glass layers (both 25% of the wall area) …etc.

8- It is recommended to use the passive solar heating systems of all their forms in spite of their high cost of establishing because they save energy and protect environment from the detrimental gaseous emissions.

9- The passive solar heating systems are the main base towards the low-energy buildings and the low-carbon-emission ones.

7- Conclusion :

The research aims at providing the energy used in heating and in air-conditioning and linking such solutions with the necessity to attain and maintain the internal thermal comfort level using the passive solar heating system by considering to change the Trombe wall components in order to reach the selection of the optimal components for such Wall to reduce as much as possible the thermal load in winter which reflects on reducing of the cooling load in summer , hence the gaseous emissions detrimental to environment are reduced as a result of reducing of the fossil fuel combustion and the electricity

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